

Physical Forcing of Phytoplankton Population Abundance in the Western Gulf of Maine

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LONG-TERM GOAL

The goal of this study is to understand the physical-biological interactions that control phytoplankton distributions observed in the western Gulf of Maine.

OBJECTIVES

The primary objective is to create realistic three-dimensional regional simulations of phytoplankton biomass which resolve time scales from hours to seasons and spatial scales ranging from 1 to 100km. The simulations are to be rigorously calibrated with available data. Once validated, the numerical solutions will be used as a basis for diagnosis of the physical-biological mechanisms responsible for producing spatial and temporal variability in phytoplankton abundance. In particular, the influences of buoyant river plume dynamics and wind-driven coastal upwelling/downwelling are to be examined.

APPROACH

- (1) Formulate a simple biological model that captures the main ecosystem dynamics that control phytoplankton abundance.
- (2) Apply the model in 1-D to the physical conditions in the Gulf of Maine to test the model's ability to simulate the observed seasonal cycles, and in order to get a basic understanding of the 1-D physical-biological interactions.
- (3) Revise the biological model as necessary and calibrate the model parameter values until satisfactory comparison with the observations is attained. Because the 1-D model does not include 3-D effects which contribute to the observed variations, we do not expect perfect agreement. However, this exercise will provide a biological model and set of parameter values suitable for use as a starting point for the 3-D simulations.
- (4) Incorporate the biological model into the 3-D circulation model.

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(5) Conduct data-driven coupled 3-D simulations of phytoplankton biomass in the western Gulf of Maine.

(6) Diagnose from the simulations the key physical-biological interactions that control phytoplankton abundance, including the observed temporal and spatial anomalies.

WORK COMPLETED

Observations available in the Gulf of Maine were pooled and analyzed. Three-dimensional maps were developed for biological and hydrodynamic quantities, derived from a compilation of hydrographic and nutrient data made available by D. W. Townsend (available at <http://oracle.er.usgs.gov/GoMaine/microplankton/micropla.htm#Data>), described in Garside et al. (1996), and a bimonthly climatology of chlorophyll data by O'Reilly and Zetlin (1996). One-dimensional time series were constructed for Wilkinson Basin and Georges Bank.

A biological model was formulated, tested and revised; various alternative formulations were tested; parameter values were calibrated.

One-dimensional simulations were conducted for Wilkinson Basin and Georges Bank, as extreme and opposite examples of the range of physical environments found in the Gulf of Maine.

The biological model was fit to the 1-D time series data using an optimization scheme developed by G. Evans (Fasham and Evans, 1995).

RESULTS

It was found that the nutrient data set, when mapped spatially and temporally using a variety of scales and methods, was generally too sparse and variable to give a reasonable-looking 3-D seasonal climatology. Relationships between nutrients and temperature and/or salinity data will need to be used to bootstrap the nutrient data to create 3-D nutrient fields for use in and comparison with the 3-D model.

A biological model was derived, which includes five state variables: nitrate, ammonium, phytoplankton, zooplankton and detritus. Parameterizations include a quadratic zooplankton loss term, and a phytoplankton-dependent factor for the fraction of zooplankton losses going to ammonium versus detritus.

A good fit to the 1-D time series data in Wilkinson Basin was obtained. Wilkinson Basin is generally similar to the open ocean: nutrients are primarily delivered from below, with low surface nutrients and productivity in summer due to stratification, and spring and fall blooms occurring due to the onset of stratification/destratification.

It was not possible, however, to obtain a good fit to the Georges Bank data using a 1-D model. The water column on Georges Bank is well mixed throughout the year. As such, in the 1-D model, nutrients are always plentiful within the euphotic zone, and productivity follows the seasonal cycle of solar insolation, which is highest in summer. This is at odds with the observations, which show spring and fall blooms on the bank. Furthermore, the observations suggest that the vertically-integrated nitrogen ($N+P+Z+A+D$) is not constant with time, but has a seasonal cycle. This suggests that either lateral

advection of nutrients or seasonal storage of organic nitrogen in the sediments is important in explaining the observed nitrogen cycle on the bank. As the sediments on the bank are frequently resuspended due to tidal action, it is likely that lateral advection is the explanation. As such, a good simulation of the seasonal nitrogen cycle on the bank is not expected without a 2-D or 3-D model. The same conclusion holds for other shallow locations which are vertically-mixed and yet exhibit a seasonal cycle in vertically-integrated nitrogen.

The optimization scheme suggests the optimal model and parameter values to use to best fit the data; these are therefore the starting point for the values to be used in the 3-D simulations.

It was found that predator-prey oscillations exist in a particular part of the solution space, depending on parameter values. It was also found that the fit of the model to the data in the mixed layer was degraded by trying to also simultaneously fit deep ocean data. This underlines the need to weight the misfit to data relative to observational error or importance, so that the data of interest is fit more closely.

IMPACT/APPLICATIONS

(1) Water Column Optics. Both phytoplankton pigments and their excreta (specifically, dissolved organic material) strongly affect the transmission of light in the sea. Knowledge of the fundamental physical-biological interactions which control phytoplankton biomass variations is essential to development of the capability to predict these optical properties of the water column which can vary tremendously over short distances.

(2) Acoustics. While phytoplankton do not materially affect the propagation of underwater sound *per se*, predators higher up the food chain most certainly can. For example, certain types of gas-bearing zooplankton (e.g. siphonophores) are potential sources of reverberation in sonar systems. Because phytoplankton production is the ultimate energy source for these higher trophic levels, it is reasonable to expect that research of this type could lead to a better understanding of the patchiness of these acoustically significant organisms.

(3) Modeling and Data Assimilation. Realistic, data-driven models which couple physical circulation to biology, chemistry and acoustics are now just becoming feasible in the coastal ocean. As these methodologies mature, they will provide a basis for the development of real time environmental information and prediction systems which could be quite valuable to Naval operations.

TRANSITIONS

The results of this work will be made available to two major programs currently investigating plankton dynamics in this region:

(1) U.S. Globec Georges Bank Study. Although specifically focused on zooplankton and fish larvae, this program could benefit from information obtained here because phytoplankton are the ultimate source of nutrition for these higher trophic levels.

(2) ECOHAB-GOM. This effort is aimed at understanding blooms of the toxic dinoflagellate *Alexandrium*, spp. which are known to cause paralytic shellfish poisoning (PSP). Despite the fact that

Alexandrium is generally a small component of the total phytoplankton biomass, our research may help to provide a larger ecosystem context for interpretation of their results.

RELATED PROJECTS

1 - The results of this effort are being fed directly into Dr. McGillicuddy's ONR Young Investigator Program award, which subsumes the balance of this project.

2 - Dr. McGillicuddy is a PI in the U.S. Globec Georges Bank program, in which he is modeling the population dynamics of *Calanus finmarchicus* and *Pseudocalanus*, spp.

3 - Dr. McGillicuddy is also involved in ECOHAB-GOM, in which he is using 3-D coupled models to examine the physical-biological interactions controlling *Alexandrium* blooms.

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PUBLICATIONS

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Abstract

This one-year contract initiated work on a longer-term project which is now being supported by Dr. McGillicuddy's Young Investigator Award. The long-term goal is to understand the physical--biological interactions that control phytoplankton distributions observed in the western Gulf of Maine. The approach is to create realistic three-dimensional regional simulations of phytoplankton biomass which resolve time scales from hours to seasons and spatial scales ranging from 1 to 100km.

The simulations are to be rigorously calibrated with available data. Once validated, the numerical solutions will be used as a basis for diagnosis of the physical--biological mechanisms responsible for producing spatial and temporal variability in phytoplankton abundance. In particular, the influences of buoyant river plume dynamics and wind-driven coastal upwelling/downwelling are to be examined.

In this first phase of the work, a biological model for the Gulf of Maine was formulated, tested and calibrated using available observations. One-dimensional simulations were conducted for Wilkinson Basin and Georges Bank, as extreme and opposite examples of the range of physical environments found in the Gulf of Maine. The biological model was then incorporated into the Princeton Ocean Model and exploratory three-dimensional coupled simulations were carried out.